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EXTENDING PASSIVE PAMPERS FUNCTIONALITY FOR SPECIFIC RIDE AND HANDLING REQUIREMENTS

ZWIĘKSZENIE FUNKCJONALNOŚCI PASYWNYCH AMORTYZATORÓW DLA SZCZEGÓLNYCH WYMAGAŃ DOTYCZĄCYCH KOMFORTU I KIEROWALNOŚCI POJAZDÓW

Abstract

Three innovative approaches to passive automotive dampers, i.e.: compression balance, super degressive and super progressive valve systems, are described. Scope of the considerations is limited to compression characteristics of a telescopic hydraulic twin tube dampers, used in chassis systems. Exemplary results from indoor, outdoor tests and computer aided analyses are presented, illustrating how further can comfort-handling-roadholding conflict be improved by extending capabilities of regular passive dampers.

Keywords: *passive damper*, *compression damping force*, *ride and handling compromise*

Streszczenie

W artykule opisano trzy innowacyjne technologie stosowane we współczesnych pasywnych amortyzatorach zawieszeń samochodowych, tj. balans na kompresji, zawór degresywny oraz zawór progresywny. Zakres artykułu ograniczono do charakterystyk sił tłumienia na kompresji teleskopowego amortyzatorów hydraulicznych o budowie dwururowej. Przykładowe wyniki dotyczą eksperymentów laboratoryjnych, poligonowych oraz symulacyjnych, które ilustrują postępowanie w celu dalszej poprawy konfliktu pomiędzy bezpieczeństwem i komfortem podróżowania pojazdem.

Słowa kluczowe: *pasywny amortyzator*, *siły tłumienia na kompresji*, *kompromis komfort–stateczność*

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1. Introduction

Damper (shock absorber) is one of the most crucial vehicle components used in chassis systems. Dampers dissipate mechanical energy converting it into thermal energy, thus reducing vibration amplitudes of car body and wheels, influencing on car active safety, reliability and occupants comfort.

In order to meet today's automotive market demands damper suppliers must take advantage of fresh ideas and the newest technologies at all of the product development and production stages. Following this strategy, Delphi [6], one of the biggest Original Equipment Manufacturer (OEM), has opened in 2000^{th} its Technical Center in Kraków (Fig. 1) as a global engineering center for passive dampers, damper mounts and damper modules. This center consists of 200 engineers and technicians working in CAD/FEA/Simulation Engineering, prototype center, testing lab, valving lab, metrology lab, material lab, ride van/ride kits/ride session support. Main areas of engineering activities are the following: research and development, product engineering, process engineering, quality engineering, industrial engineering, prototyping, full scope of verification and validation testing.

Fig. 1. View on Technical Center Kraków, Delphi SA Poland
Rys. 1. Widok Centrum Technicznego Kraków, Delphi SA Poland

Most of telescopic hydraulic dampers are built according to twin tube design principle, presented in Fig. 2, and basically consists in: 2 steel cylinders (inner and outer); 3 chambers (compression, extension and reservoir); 2 two-way valve assemblies (on piston and cylinder end); 2 fluids (oil and gas-nitrogen); and 2 seal systems (on piston and rod guide).

A hydraulic damper can be first of all characterized by a relation between damping forces (compression and rebound) and relative velocity of damper rod with respect to the damper body [1]. This type of characteristic, presented in Fig. 3, is sometimes called "backbone" or "steady-state", because only peak force and peak velocity values are taken from the damper response on a test rig with kinematic sinusoidal excitation, described by constant amplitude or frequency. In this way the damper dynamics is omitted from its response. A passive damper is described by constant parameters (curves), independent on the vehicle state. A few regions can be distinguished in the damping force vs. velocity curve (Fig. 3) that strongly influence on vehicle ride and handling [3] by the following features: (zone 1) transmission of road texture (harshness/plushness/isolation) and low speed body movements; (zone 2) body control – heave, roll, pitch and handling; (zone 3) handling and wheel control; (zone 4) managing extreme events.

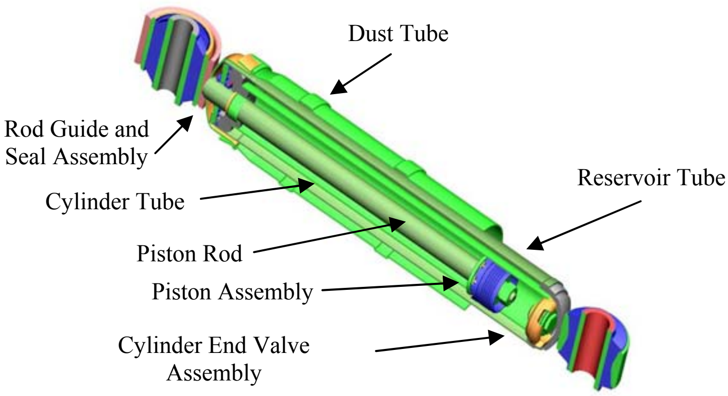

Fig. 2. Cross section of twin tube damper (shock) with piston and base valves
Rys. 2. Przekrój dwururowego amortyzatora z zaworem tłoka oraz z zaworem dolnym

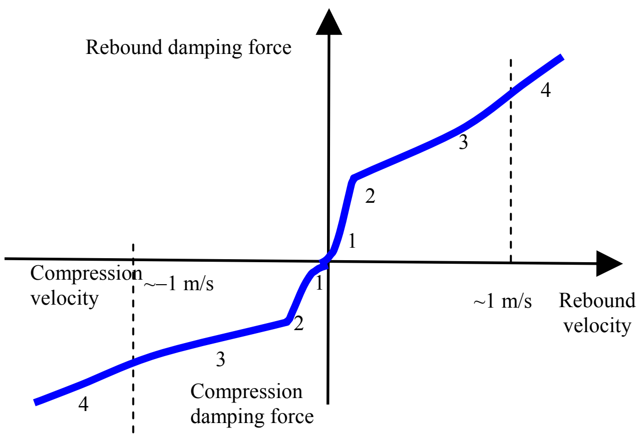

Fig. 3. Typical "backbone" characteristic of damping force vs. velocity for a passive damper
Rys. 3. Typowa „szkieletowa” charakterystyka sił tłumienia w funkcji prędkości
dla pasywnego amortyzatora

The compromise between car ride and handling can be significantly improved with semi-active dampers [1], which have switchable damping characteristics controlled by a computer unit observing the vehicle current state. However, passive dampers are still in c.a. 95% of automotive applications and this will not change quickly.

The goal for Delphi is to supply some innovative and cost effective valve designs that more fully utilize performance of passive dampers. Desired performance features of dampers in compression stroke are defined by the following targets [3]:

- decoupling between low and medium speed tuning parameters,
- smooth transition (knee point) from low to medium speed,
- degressivity of damping forces in mid-to-high velocity range,
- progressivity of damping forces in high velocity range for car body structure protection during extreme road impacts.

Active safety and comfort are two main considerations in damper tuning (trade-off) for a selected car with a given chassis system and a brand philosophy. Parallel to car road tests, performed by qualified ride engineers in different road conditions, tests and analyses in virtual environment are also carried out. This process, repeated in a closed loop, enables in comprehensive and effective manner to meet the target in fewer steps. A reasonable vehicle model, used for computer aided damper selection, should include [2, 4, 5]:

- car body (sprung mass) as a rigid body, with seats and occupants,
- car suspension models linking unsprung masses with the car body,
- accurate models for suspension elastic components (springs, jounce bumpers, etc.),
- accurate model for damper including flow through the valves and bypasses, damping medium properties among the others,
- road with unevenesses assumed usually to be rigid,
- tire model describing its radial characteristics with short length road profile filtering properties and one-sided constraints.

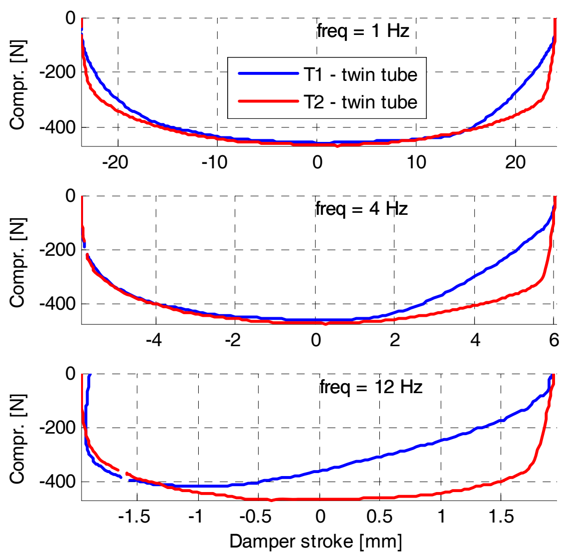

Fig. 4. Damping force vs. stroke characteristics (compression force only) measured for dampers T1 and T2 on test rig with sinusoidal kinematic excitation (max velocity = const; freq. = 1, 4 and 12 Hz)

Rys. 4. Charakterystyki sił tłumienia na kompresji w funkcji skoku, zmierzone dla amortyzatorów T1 i T2 na stanowisku z kinematycznym wymuszeniem sinusoidalnym

The paper main goal is to present how further can comfort-handling-roadholding conflict be improved using some innovative approaches to passive dampers. Scope of the considerations is limited to compression characteristics of a telescopic hydraulic twin tube dampers. Exemplary results from indoor and outdoor tests and computer aided analyses are presented.

2. Compression balance in twin tube dampers

The term Compression Balance ($0 \leq CB \leq 1$) in twin tube dampers concerns utilization rate of the piston valve relative to the base valve during the compression stroke [3]. The higher compression balance is, the higher hydraulic resistance of the piston valve. At limit, when CB approaches unity, cavitation phenomenon can arise in the extension chamber due to exceed of permissible pressure drop across the piston, what strongly deteriorates the damper functionality. The compression balance is a powerful tool to optimize car ride and handling, but requires a tunable piston compression valve.

In order to illustrate this phenomenon two dampers (T1 and T2) were prepared to achieve the same level of peak damping forces (like in Fig. 3), but with a quit different compression balance utilized ($CB \approx 0{,}1$ for T1 and $CB \approx 0{,}8$ for T2), what significantly reflects on different impact on vehicle dynamics. Comparison of characteristics of damping forces vs. stroke (compression force only) obtained for the dampers (T1, T2) on a test rig with sinusoidal kinematic excitation, described by constant maximal velocity (150 mm/s) and variable frequency (f = 1, 4 and 12 Hz), is presented in Fig. 4, where the compression force evolves form the right to the left. The following criteria for the dampers evaluation can be defined (Fig. 4): (i) peak compression force in the given test cycle and (ii) energy dissipated by the damper, measured as an area between the considered curve and horizontal zero-axis. Damper T1, with lower compression balance, looses its effectiveness much earlier than the damper T2 when the excitation frequency is increased (Fig. 4).

Compression balance in twin tube dampers impacts its performance at higher frequencies ($f \approx 12$ Hz) responsible mainly for secondary ride control and road holding, what was confirmed by road tests [3]. Twin tube damper with high CB is more responsive and its efficiency is closer to the monotube dampers. Damper with low CB is described by better isolation properties. The compression balance is another design parameter used for a vehicle tuning.

3. Super degressive valve system

A typical characteristic of damping force vs. velocity of hydraulic damper (Fig. 3) is usually described by a sharp transition in vicinity of knee point and a progresivity starting at medium range of velocities. An improved damper with respect to comfort criterion should be described by a steady-state compression damping curve like the one (desirable) in Fig. 5, which can be achieved only with specially redesigned valves.

Delphi's Super Degressive Valve System consists in blow-off piston compression valve together with deflective disc base valve, that provide the best match to the required performance characteristics. Variable orifice system improves low speed control (Fig. 5, zone 2). Valves with low hydraulic restrictions are used to obtain a degressive force characteristic at higher piston velocities (Fig. 5, zone 3).

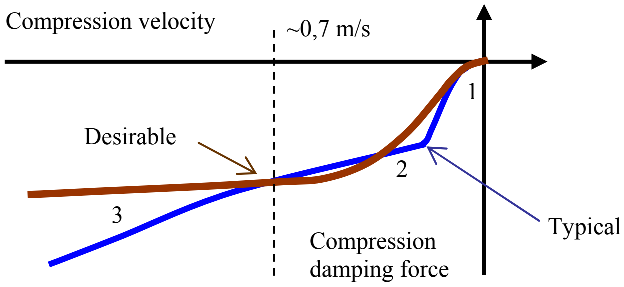

Fig. 5. Comparison of a typical and desirable characteristics of damping force vs. velocity
Rys. 5. Porównanie typowej i pożądanej charakterystyki sił tłumienia w funkcji prędkości

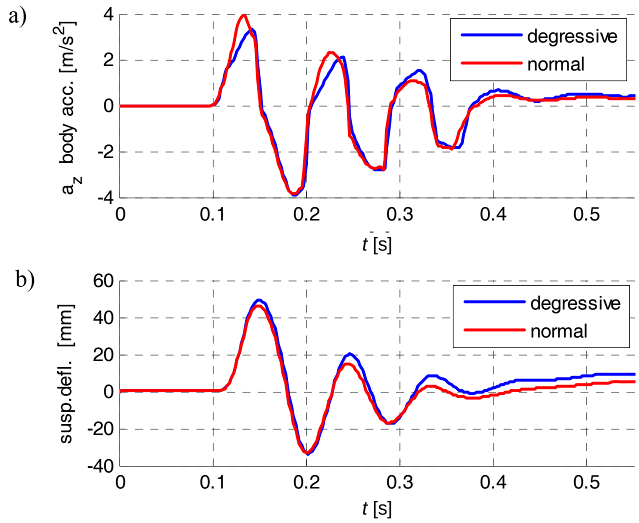

Fig. 6. Time results of vehicle passing over single road bump simulation with typical and degressive dampers: a) vertical accelerations of the car body (front axle position), b) deflections of front axle suspension
Rys. 6. Wyniki czasowe symulacji przejazdu po pojedynczej nierówności dla pojazdu z amortyzatorami typowymi oraz degresywnymi: a) przyspieszenia pionowe nadwozia nad przednią osią, b) ugięcia przedniego zawieszenia

An influence of degressive damper on vehicle dynamics can be illustrated by using a half-car simulation model. Samples of time results of virtual vehicle (1,5 tons) response [3], passing over single road bump with medium height (described by: v_x = 74 km/h; bump length = 1 m; bump height = 0,04 m) with typical and degressive dampers, are presented in Fig. 6. First two peaks of positive vertical accelerations of the car body (Fig. 6a)) at front axle position are decreased for the considered excitation by c.a. 30% due to the degressive damper, improving comfort and impact absorption properties. This can happen only at cost of an increased front suspension jounce deflection (Fig. 6b)) by c.a. 5%, necessarily in the suspension linear range (before jounce bumper engagement point). The presented features of Super Degressive damper were also confirmed by results of road tests.

4. Super progressive valve system

Comfort orientated damping compression curve can to often cause a crash-through phenomenon in the car suspension at extreme events, generating dangerous impact loads in the car structure and high accelerations acting on vehicle occupants.

The following innovative add-on valve system designed by Delphi, called Super Progressive, enables to rapidly increase damping compression force after reaching certain threshold of the piston velocity, and to sustain the selected force level until very end of the compression stroke. This SP operation principle is illustrated in dynamic characteristic of damping force vs. velocity, shown in Fig. 7, where a regular damper response with the same basic valve code is superimposed for the comparison. The both dampers (Fig. 7) generate at the test rig the same damping force in the rebound stroke. The same applies for the compression forces, but only in a comfort zone, i.e. for velocities lower than Super Progressive threshold (usually greater than 2,0 m/s) matched for a given vehicle.

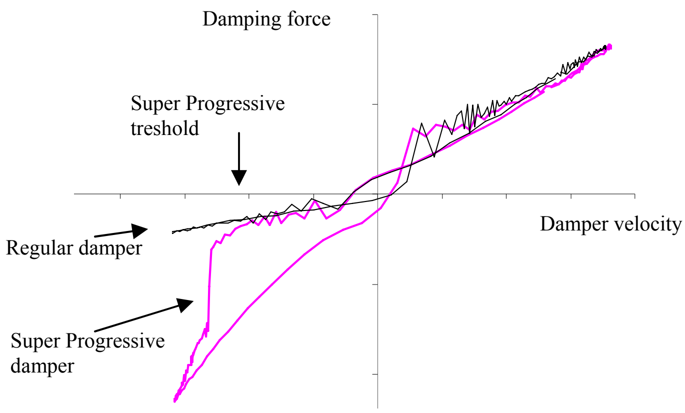

Fig. 7. Comparison of dynamic characteristics of damping force vs. velocity for regular and Super Progressive damper, measured at test rig

Rys. 7. Porównanie dynamicznych charakterystyk sił tłumienia w funkcji prędkości dla amortyzatora standartowego oraz typu Super Progressive, zmierzonych na stanowisku

In order to illustrate an influence of Super Progressive damper on vehicle dynamics the half-car simulation model can also used. The following simulation results concern conditions of passing over a single road bump ("sleeping policeman") with significant height (described by: v_x = 40 km/h; bump length = 2 m; bump height = 0,12 m) by a medium-size car with regular and Super Progressive dampers.

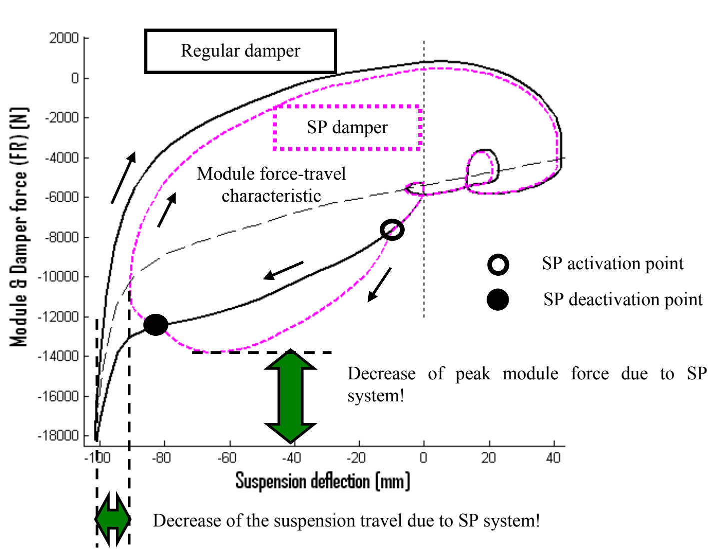

Fig. 8. Net forces transmitted the car body by spring-damper module as a function of the suspension deflection. Simulation results of passing over a single road bump by car with regular and SP dampers

Rys. 8. Zależność siły przenoszonej przez moduł sprężysto-tłumiący zawieszenia w funkcji jego ugięcia. Symulacja przejazdu po nierówności dla samochodu z amortyzatorami standardowymi oraz typu SP

Benefits of SP system can be confirmed focusing on some parameters describing operation of the front suspension for the considered event. Relationship of net forces (F_n) transmitted the car body by spring-damper module as a function of the suspension deflection s (s = 0 corresponds to the suspension design position with the wheel load $F_n = -6{,}1$ kN) is presented in Fig. 8. In case with the regular damper, high energy of the excitation was insufficiently dissipated. Most of this energy had to be absorbed by the suspension spring and jounce bumper yielding a large suspension deflection in jounce (s = –100 mm) and extreme peak force (F_n = –18,4 kN) at the stroke end. In case of SP system, additional compression force is generated by the damper early after impact arise, when compression velocity exceeds SP activation point, marked in Fig. 8. The unsprung mass is decelerated smoothly before reaching full compression position. Peak net force (F_n = –13,8 kN) is decreased by c.a. ~30%, thus reducing the loads on vehicle structure. It is achieved with a decrease of the suspension deflection ($s \approx -90$ mm) by c.a. ~10%, avoiding the suspension bottoming out. Experiences from the road tests confirm the mentioned advantages of SP system, which is ideally suited e.g. for off-road applications.

5. Summary

Dampers used in car chassis are defining most evident vehicle performance attributes in terms of comfort and handling. Car manufactures are very often using only damper settings to create sport or comfort versions in order to diversify their product. Damper performance is a common tool highlighting vehicle performance features typical for particular car manufacturer.

Three innovative approaches developed by Delphi are described, that more fully utilize performance of passive dampers making them closer the current market demands. Fall of passive dampers is still a long way, because they can be characterized by 80% performance of semi-active dampers at 10% of their cost.

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